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PROGRESSIVE DEGENERATION OF THE LATERAL-LINE NERVE IN THE CATFISH

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That the distal portion of a peripheral nerve, when separated from its ganglionated part, ordinarily undergoes complete degeneration, has long been known. This secondary degeneration has been recently discussed in all its details by Spielmeyer (1929) who has pointed out an important difference of opinion among workers as to the nature of this process. The majority of investigations, including such important students of the subject as Ramón y Cajal (1928), claim that the degenerative process affects the whole of the peripheral fragment *simultaneously*. Other workers, equally well known and including such men as Bethe, maintain that the degenerative process is a *progressive* one which, beginning at the cut surface, proceeds to the distal end of the severed fragment. The solution of this question seems to be far from accomplished. It is perhaps to be attempted best with the medullated nerves of cold-blooded vertebrates.

Some years ago Brockelbank (1925) reported that when the lateral-line nerve of the catfish, Ameiurus nebulosus, was cut, the lateral-line organs associated with the nerve degenerated and that as a rule those near the cut degenerated before those more distant from it. These observations suggest that the degeneration of the nerve, which secondarily induces the degeneration of the lateral-line organs, is not a simultaneous operation but a progressive one. To ascertain the facts in the case we have undertaken directly the study of the degeneration of the lateral-line nerve in Ameiurus and we report the following results.

Relatively large catfishes were selected and their lateral-line nerves were cut immediately behind the gills. These fishes were retained in an aquarium and were then killed at regular daily intervals. Their lateral-line nerves were prepared in 1 per cent osmic acid, care being taken not to include the portion immediately following the cut end. Pieces of the nerve not far from the cut were compared with other pieces as far from it as possible. The nerve was found to have undergone typical Wallerian de-

generation, as has already been described by Williams (1930). Since it was suspected that temperature might play an important part in the process, the experimental fishes were kept in water held continuously as nearly 18°C. as could be easily managed.

Attention was centered on the degeneration of the myelin sheath. The degeneration in this sheath was first clearly noticed about ten days after the operation and at this stage the far and near pieces of nerve were indistinguishable. The change in the sheath material consisted in the usual thickenings, contortions and other such irregularities in the myelin substance. There was almost no fracturing or formation of ellipsoids at this stage. At fourteen days the near and far pieces of nerve were unmistakably different, the far pieces being always less advanced in degeneration than the near ones. If at this period the whole nerve was cut into several pieces, these could be easily placed in sequence as determined by their degree of degeneration. For several days after this the difference between the two extreme pieces of the nerve remained readily discernible, but in preparations made from nerves eighteen to twenty days after the operations in which myelin degeneration was greatly advanced, no difference between the two extremes could be discovered. These observations lead us to conclude that secondary degeneration as indicated by changes in the myelin is in reality a progressive process in that at an appropriate stage the degeneration can be shown to move peripherally over the nerve.

We were interested naturally to determine, if possible, a rate for this change. The difficulty in making this determination was that the whole process involved no sharp turning points and that consequently it was not easy to establish beginning and end points. Close comparisons of two nerves from the same fish prepared on different days and therefore supposedly different in their extent of degeneration led us to conclude that the degenerative process when open to most favorable observation proceeds distally over the nerve at a rate of approximately two centimeters a day. Although this rate is of necessity very roughly determined, it is evidently of so different an order of magnitude from that of the true nerve impulse even in cold-blooded animals that these two types of impulses must be regarded as quite dissimilar. The nerve impulse, relatively rapid in its transmission, appears to be an ionic readjustment on the surface of the neurite. The degenerative wave, very slow in its progress, must be a progressive metabolic change. It probably depends upon the cessation of a supply of something, probably a material of some kind, from the nucleated region of the neurone which material is gradually drained off at the distal ends of the fibres. This view, hypothetical as it is, is nevertheless consistent with the rate at which the change passes over the fibre and is suggested notwithstanding the fact that Wible (1925) was not able to detect the passage by capillarity of veratrin over the sciatic nerve of the

frog. How this hypothetical substance is transmitted over the fibre is not known. The senior author has suggested elsewhere (Parker, 1929a, 1929b) that such transmissions may be accomplished by the so-called neurofibrillar systems of neurones and that these transmissions constitute the true functions of such systems.

M. C. Brockelbank, "Degeneration and Regeneration of the Lateral-line Organs in Ameiurus nebulosus (Les.)," *J. Exp. Zoöl.*, **42**, 293–305 (1925).

G. H. Parker, "What Are Neurofibrils?" *Amer. Nat.*, **63**, 97–117 (1929a).

G. H. Parker, "The Neurofibril Hypothesis," *Quart. Rev. Biol.*, **4**, 155–178 (1929b).

S. Ramón y Cajal, *Degeneration and Regeneration of the Nervous System.* Trans. by R. M. May. Oxford, 2 vols. (1928).

W. Spielmeyer, "Degeneration und Regeneration am peripherischen Nerven," Bethe, A., G. von Bergmann, G. Embden, A. Ellinger, *Handb. norm. path. Physiol.* **9**, 285–338 (1929).

C. L. Wible, "The Locus of the Action of Veratrin in the Sciatic Nerve of the Frog," *Proc. Soc. Exp. Biol. Med.*, **22**, 336–337 (1925).

S. C. Williams, "Regeneration of Peripheral Nerves in Amphibia Studied with the Aid of a Vital Stain," *J. Exp. Zoöl.*, **57**, 145–181 (1930).

THE RELATION OF TASTE-BUDS TO THEIR NERVE-FIBRES

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Amid the mass of evidence concerning the rôle played by the nervous system in the phenomena of degeneration and regeneration, no more consistent results have been obtained than in the case of taste-buds. As long ago as 1876 Vintschgau and Hönigschmied found that the severance of the glossopharyngeal nerve on one side of a dog's head brought about the disappearance of the taste-buds on the corresponding side of the tongue. Those on the other side were in no way affected. This degenerative process, verified many times since on mammalian material, was found by Olmsted ('20a, '20b) to occur also in fishes. Not only did the gustatory organs disappear, when cut off from their nervous supply, but reappeared coincident with the arrival of regenerated nerve-fibres. The presence of taste-buds was thus declared to be dependent upon the presence of a normal nerve, since the "buds" degenerated and disappeared when the nerve degenerated, and reappeared when the nerve had regenerated.

To account for this dependence, Olmsted suggested that some chemical substance, hormone-like in character, was constantly being given out by the nerve-fibres to the sense cells. The normal status of a taste-bud was maintained only so long as it received a supply of this substance. The

elimination of the supply by cutting the nerve was sufficient to cause the disintegration of the sense-organ. Restoration of the nerve and the chemical secretion meant the restoration of the taste-bud.

May ('25) interpreted the results of his investigations in a like manner, and Parker ('22, p. 128) has suggested that the same explanation may apply in the embryology of these organs.

In the course of a series of experiments dealing with this problem and carried on under the direction of Prof. G. H. Parker, certain significant facts relative to the metabolism of nerves have been forthcoming. It is my purpose in this preliminary paper to report these observations very briefly together with some theoretical considerations based upon them, leaving a more detailed account of these and other findings for later publication.

At ordinary room temperature, about 20°C., the taste-buds on the barbels of the catfish, Ameiurus nebulosus, disappear within eleven days after the branches of the seventh nerve leading to these barbels have been cut. Strangely enough, the actual disintegration of the sense-organs requires no more than twenty-four hours. Ten days after the appropriate nerve has been cut, for example, the taste-buds may be, to all appearances, perfectly normal; other preparations made from the same animal on the eleventh day will show a complete absence of them. This state of affairs becomes all the more striking when the temperature is lowered. Instead of the twenty-four hour period being lengthened, its initiation is merely postponed. At a temperature of 10°C., which delays the disappearance of buds until the twentieth day, they can still be found on the nineteenth. Temperature levels ranging above 20°C. bring about an expected earlier elimination of the gustatory organs. But once again the actual organismal disintegration is confined to twenty-four hours.

A calculation of the temperature characteristic from 10°C. to 20°C. would reveal a Q_{10} of approximately 2, the ideal figure as postulated by van't Hoff's rule. Such a calculation, however, should be based on temperatures controlled more accurately than I have had occasion to do.

Two important conclusions follow from this information. (1). The time of disappearance of taste-buds is directly influenced by temperature. (2) That influence is directed against some physiological or nutritional prerequisite of normal taste-buds, for at all temperatures the actual disintegration of cell structure proceeds at the same rate.

To me this so-called physiological prerequisite assumes the form of a chemical material present in nerves which is necessary for the maintenance of normal taste-buds. This material is likewise conceived of as being *identical with that necessary for the maintenance of the nerve itself.*

During the natural existence of a nerve, certain metabolic changes are constantly taking place, with the utilization of oxygen and production of carbon dioxide. Such chemical activity presupposes the existence of the

necessary reacting materials. Even in severed nerves none of the usual foodstuffs can be thought of as being deficient so long as the blood-supply is intact. The required substances must, therefore, come from the cell bodies and diffuse along the nerve-fibres. When a nerve is cut, the usual metabolic activities are dependent upon the supply of nutriment locally available.

As long as any of this hypothetical material is present in the nerve, the taste-buds, morphologically at least, are normal. But once the supply is used up or reaches a certain minimum, a point correlated with a state of maximum myelin degeneration, the disintegration of the buds themselves takes place. This latter process goes on, as we have seen, independently of temperature and runs to completion by the end of twenty-four hours.

This conception finds verification in an experiment whereby the nervous elements were removed as completely as possible from a barbel and the taste-buds were found to have disappeared thirty-six hours later. When the nerve was removed, so was its influence. Ideally, of course, the taste-buds should have been absent at the end of twenty-four hours. That they "hang on" somewhat longer can be attributed to minor nerve branches which it is impossible to remove and which supply the necessary nutrient materials for those few extra hours.

The conception is likewise in agreement with the evidence concerning the phsyiology of nerves, both normal and degenerating. During activity the metabolic changes in a nerve-fibre are greatly increased. Parker ('28) has shown that the production of carbon dioxide in the lateral-line nerve of the dogfish rises to about fifteen per cent following electrical stimulation. More recently, Cook and Gerard ('31) have stated that a cut nerve loses its ability to conduct more rapidly when stimulated than when at rest. It is a matter of common knowledge that the nerves of warm-blooded animals degenerate with greater rapidity than those of cold. The difference is strikingly reflected in the relative times of disappearance of taste-buds in mammals and fishes. Whereas the initiation of changes in the gustatory organs of rabbits can be measured in hours, we already know that ten days is the approximate beginning of degeneration in a catfish kept at room temperature. Finally, frog nerves degenerate more rapidly at high temperatures than at low. The Q_{10} from 14°C.–24°C. is 2.2 (Rindovie, '25), which happens to be exactly that of the respiratory rate (Gerard, '27).

One remaining manifestation of this chemical hypothesis comes to mind. If such substances are actually present, it is reasonable to suppose that a centrifugal degeneration of nerve and subsequent centrifugal disappearance of taste-buds would prevail. That is to say, the supply of nutrient material would be used up first in the proximal portion of a severed nerve and so on along its length. This state of affairs in nerve has already been reported in these PROCEEDINGS by Parker and Paine (1931). As for the taste-buds, the results are less striking but likewise consistent.

Because the actual degenerative period of taste-buds is so short, it is difficult to isolate except under carefully controlled temperature conditions. Great numbers of catfish barbels were fixed and sectioned during the so-called "crucial" period, and the relative percentages of normal, partly degenerated, and completely degenerated taste-buds at different levels computed. Without quoting figures, it is sufficient to say that in many cases an actual state of degenerative progression from base to tip was discernible. For many others, however, the figures were indifferent. No preparation showed a reverse progression.

While these last results are not so clear-cut as some others, they certainly are not contradictory to the chemical hypothesis. On the contrary, even with their limitations, they are the most literal expression of our hypothesis of a diffusing chemical so far uncovered.

D. D. Cook and R. W. Gerard, "The Effect of Stimulation on the Degeneration of a Severed Peripheral Nerve," *Amer. J. Physiol.*, **97**, 412–425 (1931).

R. W. Gerard, "Studies on Nerve Metabolism. II. Respiration in Oxygen and Nitrogen," *Amer. J. Physiol.*, **82**, 381–404 (1927).

R. M. May, "The Relation of Nerves to Degenerating and Regenerating Taste-Buds," *J. Exp. Zoöl.*, **42**, 371–410 (1925).

J. M. D. Olmsted, "The Nerve as a Formative Influence in the Development of Taste-Buds," *J. Comp. Neur.*, **31**, 465–468 (1920a).

J. M. D. Olmsted, "The Results of Cutting the Seventh Cranial Nerve in Ameiurus Nebulosis (Lesueur)," *J. Exp. Zoöl.*, **31**, 367–401 (1920b).

G. H. Parker, *Smell, Taste and Allied Senses in the Vertebrates.* Philadelphia and London, 1922.

G. H. Parker, "Carbon Dioxide from Nerves of Cold-blooded Vertebrates," *Amer. J. Physiol.*, **86**, 490–504 (1928).

G. H. Parker and V. L. Paine, "Progressive Degeneration of the Lateral-Line Nerve in the Catfish," *Proc. Nat. Acad. Sci.*, **17**, 589–591 (1931).

A. Rindovie, *Ann. di clin. med. e di med. sperim.*, **15**, 60 (1925).

M. von Vintschgau and J. Hönigschmied, "Nervus Glossopharyngeus und Schmeckbecker," *Arch. ges. Physiol.*, **14**, 443–448 (1876).

THE COLOR CHANGES IN THE SEA-URCHIN ARBACIA

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Activated color changes, whereby animals may adapt themselves more or less quickly to their surroundings, are known to occur in cephalopods, in crustaceans, and in cold-blooded vertebrates, groups relatively high in complexity of organization. Among the simpler animals very few instances of this kind have been recorded. In the echinoderms, though the animals often show locomotor responses to light, color changes have been

mentioned, so far as I am aware, in only one species. Arbacia pustulosa, according to von Uexküll (1896, p. 330), is brown in darkness and deep black in the light. The uniqueness of this statement and the abundance of the closely related species Arbacia punctulata (Lam.) in the neighborhood of the Marine Biological Laboratory at Woods Hole led me to examine the color changes in this form.

If many specimens of A. punctulata are collected and compared, they will be found to vary from a light brown, often with an olivaceous cast, to a very deep chocolate-brown or almost black, with an olivaceous or a purplish tint. This species is in no sense dimorphic, for the two extremes in the color series are united by a set of intergrades of great completeness. The question suggested by this condition is the following: Can one individual by direct change cover this range of color differences, as is implied by von Uexküll's declaration, or are these various tints permanent characteristics of the several individuals concerned?

To test this question, nine specimens of A. punctulata were selected, which were of intermediate tint and indistinguishable in color. Three of these were placed in complete darkness, another three in a glass vessel with white walls illuminated from above by bright daylight, and the final three in a vessel similar to the last but with black walls. After ten hours all were closely compared. They were still indistinguishable in tint and, so far as could be judged, of the same color as at the beginning of the experiment. A second set was tested in a similar manner over a period of ten and a half hours and the animals were inspected, exclusive of those in darkness, once an hour. In this instance, as in the former one, no change from the original color could be detected. Similar trials were made with sea-urchins, in which all specimens instead of being intermediate in tint were either very dark or very light, and again no change in color was noticed. Finally, three very dark animals were placed in the same small aquarium with three very light ones and subjected to darkness, in one test for five and a half hours and in another for sixteen hours. A similar test was carried out with others in bright daylight. In both these sets, the colors, so far as could be judged, remained unalterably the same. All these trials were carried out in running or in fresh sea water and since they all failed to give evidence of changes of color on the part of the individuals tested, it is concluded that Arbacia punctulata does not show color changes. Since this species is very closely related to the Mediterranean form noted by von Uexküll and since his observations, judging from his record, were apparently rather incidental than complete, it is possible that he may have been in error. At least it is certain that the representatives of A. punctulata from the Woods Hole region, though individually diverse in tint, when carefully tested showed no evidence that they could change color.

Assuming the same to be true of A. pustulosa, this conclusion has im-

portant bearings on the problem of the distribution of elementary effectors in the animal kingdom. Among the multicellular animals, such effectors as muscles, glands and luminous organs occur throughout almost the whole range of forms. Cilia, otherwise widely distributed, are strangely absent from most nematodes and arthropods. Nettling cells are strictly limited to the coelenterates and electric organs to the fishes. Chromatophores with their attendant color changes are well developed only in those groups, such as the arthropods, mollusks and vertebrates, where the central nervous organs and the receptors, especially the eyes, are highly specialized. That they occur in the simpler animals at all seems extremely doubtful. At least the conclusion drawn from the present study appears to remove one of the oft-quoted instances among these forms, a fate that may overtake the second example of this kind, namely, that in sponges, as described by von Lendenfeld (1883). While it is conceivable that an animal in the course of its evolution may develop a system of color changes even though it has very inadequate photoreceptors with which to control them, such a step is highly improbable. It is very much more likely that color changes arose in only those forms in which eyes and central nervous organs had reached such a degree of specialization as to enable the possessors to respond to the details of a luminous environment. Hence chromatophores with their associated color changes are not to be expected in the simpler animals.

R. von Lendenfeld, "Ueber Colenteraten der Südsee. II. Mittheilung. Neue Aplysinidae," *Zeit. wiss. Zoöl.*, **38**, 234–331 (1883).

J. von Uexküll, "Vergleichend sinnesphysiologische Untersuchungen. II. Der Schatten als Reiz für Centrostephanus longispinus," *Zeit. Biol.*, **34**, 319–339 (1896).

EFFECTS OF ACETYL CHOLINE ON CHROMATOPHORES

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The pronounced effect of acetyl choline on smooth muscle and the high efficiency of this substance at most remarkably low concentrations (Hunt, 1918) led me to test its action on chromatophores. I used acetyl choline bromide prepared by the Eastman Kodak Company. This was made up fresh each day in an aqueous solution one part of the substance in a thousand parts of water.

On injecting one-tenth of a cubic centimeter of this solution into the body of a common killifish, Fundulus heteroclitus, weighing approximately 10

grams, the fish in course of time grew slightly darker as compared with a control animal into which an equal amount of distilled water had been injected. This treatment was repeated a number of times and always with the same result. It indicates a slight expansion of the chromatophores as compared with those in the control. On doubling doses the fishes passed into a condition of mild coma and several of them sooner or later died.

Similar tests on the common spotted frog though continued over a considerable period never brought forth any observable change in the color of the skin though the animals showed pronounced respiratory disturbances. As the concentration of the drug used in both these sets of tests, one part in a thousand, is far removed from that at which it affects smooth muscle, namely, a few parts in a hundred million, I conclude that, as far as these tests go, acetyl choline is not to be regarded as an important means in influencing chromatophores.

R. Hunt, "Vasodilator Reactions. I," *Amer. J. Physiol.*, **45**, 197–230 (1918).

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*REVERSIBLE COAGULATION IN LIVING TISSUE. VIII**

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Within the last few years it has become quite the fashion to study the cataleptoid and catatonic conditions brought about in animals by the use of the alkaloid bulbocapnine. These studies have had as their object the hope that the insight gained by studying the reactions of animals to bulbocapnine would throw light upon the perplexing problem of the human stupor syndrome. It was quite the natural thing then that the action of bulbocapnine in animals should be studied by us parallel to the work of Drs. Lang and Paterson at Willard State Hospital, and applying the theories of reversible agglomeration in which the authors have been interested.

The general trend of thought[1] seems to be that the catalepsy and catatonia produced in animals by bulbocapnine is the same as that found in cases of dementia praecox catatonic; although Bourguignon and de Jong[2] state that the catalepsy part of the picture is in reality cataleptoid as compared to human beings. This raised great hopes that in bulbocapnine we would find an extraordinarily good peptizing agent; for as was predicted,[3] and as Drs. Lang and Paterson have demonstrated, dementia praecox catatonia is a condition involving over-peptization of certain of the brain colloids.

Through the courtesy of Dr. Bedient of Merck and Company we received a sample of bulbocapnine hydrochloride. The first test of the colloidal properties of bulbocapnine was made, as usual, on an egg-white sol. The alkaloid was found to be an excellent coagulating agent. This fact predicates immediately either one of two sets of conditions: that the egg-white sol test is not in all cases a true indication of the way a drug should be expected to act in the body, and that true peptization catatonia is produced by bulbocapnine in animals; or else the egg-white test can be relied upon to represent the colloidal action of a drug *in vivo*, and the condition brought about by bulbocapnine in living things is the result of agglomeration. It will be remembered that from the data on hand, Bancroft and Richter[3] predicted that there should be two types of catatonia, one due to over-peptization, and one due to agglomeration of the protein colloids in the brain. The next lead was to the effect that bulbocapnine produces only sleep in man,[4] although this was attributed to insufficient dosage.

The dilemma was cleared up by Drs. Lang and Paterson, to whom the authors are very grateful, using Case 1 in their report, a true case of dementia praecox catatonia as was shown by his behavior with sodium amytal and sodium rhodanate. A subcutaneous injection of 150 mgm. of bulbocapnine hydrochloride in a 4% solution was made on this man. In about fifteen minutes he talked more freely than usual, and pronounced the word "no" distinctly. Upon request he wrote his name. The cataleptic condition was markedly relieved. None of these conditions obtain in his daily life. So, bulbocapnine produced a marked improvement in the case of a man already suffering from over-dispersion of certain of the brain colloids. Since the man becomes worse when given sodium rhodanate, a known peptizing agent, bulbocapnine must be an agglomerating agent in man.

Still this does not prove that the colloidal reaction of animals to bulbocapnine is the same as that of man. However, were the brain colloids of man to be agglomerated by bulbocapnine and those of lower animals peptized, it would give rise to a most awkward situation. Schaltenbrand[5] gives a clue as to what the probable situation is in lower animals. He found that large doses of bulbocapnine cause the appearance of the epileptic state. Since epilepsy is associated with agglomeration of certain of the proteins in the brain the production of epilepsy in animals by bulbocapnine indicates that it acts as a coagulating agent.

If bulbocapnine brings on the catatonic state in animals by agglomeration, sodium rhodanate and ephedrine should by their peptizing action relieve the condition. On the other hand, sodium amytal should aggravate the condition because it causes agglomeration of protein colloids. The first experiments were performed on rabbits by administering the alkaloid

intravenously; the therapeutic dose was found to be too close to the lethal dose by this method, the rabbits dying in tetanic convulsions. Accordingly five cc. of a 4% solution of bulbocapnine were injected intraperitoneally into a rabbit weighing 2700 grams. Two minutes later the pupils were constricted. In 15 minutes catatonia and the cataleptic state were well marked. The test used to determine the presence and severity of the cataleptic state is as follows: One or two fingers are placed under the lower jaw of the rabbit and the head raised slowly. This straightens out the front legs; when the support for the head is removed, the body tends to stay in the position it has been given if the animal is cataleptic. On pushing down on the back of the neck the forelegs flex; when the pressure is relieved the legs stiffen again—a normal rabbit will not do this. The reaction is like pushing down lightly on a spring. In addition to this, the animals will hold many bizarre positions when placed in them. This particular rabbit was placed with its forelegs above its head and against a brick wall; it maintained the position for more than five minutes. In addition the animal appeared stuporous.

A rabbit weighing 2200 grams was given 4.1 cc. of a 4% solution of bulbocapnine hydrochloride by intraperitoneal injection. In 30 minutes the rabbit was slightly cataleptic as indicated by the above-mentioned test. At this time 1.8 cc. of a 10% solution of sodium rhodanate was injected intravenously. A minute later the animal exhibited no cataleptic response to the usual tests. The stupor was decreased markedly after another intravenous injection of sodium rhodanate. The experiment was repeated with a rabbit that exhibited a more profound cataleptic condition; the condition of the rabbit improved immediately. The animal resisted attempts to raise its head. When its head was raised the forelegs came up off of the floor, a reaction not observed in a cataleptic rabbit. These two experiments show that the action of bulbocapnine is that of agglomeration. In order to have a double check upon the action of peptizing agents in relieving bulbocapnine catalepsy an experiment was made using ephedrine sulphate, a better peptizing agent.

A rabbit weighing 2700 grams was given an intraperitoneal injection of six cc. of a 4% solution of bulbocapnine hydrochloride. Ten minutes later an extreme condition of catatonia and catalepsy was observed. The rabbit even held a standing position with the front legs unbent and the back legs only slightly flexed, so that the underside of the animal was at least three inches from the floor. At this time one cc. of a 3% solution of ephedrine sulphate was injected intravenously. A distinct remission of the symptoms occurred in about a minute. The stuporous condition was almost abolished and the rigidity was reduced markedly. Two cc. of the ephedrine sulphate injected subcutaneously five minutes later caused further abatement of the symptoms. This leaves no doubt

that bulbocapnine produces catalepsy by agglomeration of certain protein colloids in the brain.

In order to check the argument, the effect of sodium amytal, an agglomerating agent, upon the catatonia produced by bulbocapnine was tried. A 2700-gram rabbit was given an intraperitoneal injection of six cc. of a 4% solution of bulbocapnine hydrochloride. The animal exhibited catatonia and catalepsy in 12 minutes; the condition lasted only for ten minutes, the symptoms slowly disappearing. At this time the animal was given by intraperitoneal injection 4.5 cc. of a solution (120 mg./8 cc.) of sodium amytal. The rabbit did not lose consciousness, and the bulbocapnine effect reappeared. The cataleptic condition of the rabbit was as pronounced as when it was at its height; the condition continued unabated for 15 minutes, at which time further experimentation was carried out on the animal. The experiment was checked with another animal. This time the catatonic condition was made very much worse by injecting sodium amytal.

These experiments leave little doubt but that bulbocapnine catalepsy and catatonia are similar only in symptomatology to the conditions observed in dementia praecox catatonia. In the one case the condition is brought about by over-peptization of certain protein colloids in the brain, while in the other agglomeration is the controlling factor. So, at the moment, we cannot expect to unravel the secrets of human catatonia by studying the action of bulbocapnine in animals. However, adrenaline produces catatonic phenomena[6] in mice. Due to the many similarities between the actions of ephedrine, an excellent peptizing agent, and adrenaline, it may be that adrenaline catatonia in mice is a case of over-peptization. On the other hand, adrenaline, causing sleep when injected into the brain, should involve coagulation of some proteins. The nature of adrenaline catatonia in mice will have to be determined experimentally.

So, as Bancroft and Richter[3] predicted, there are two types of catatonia, one due to over-dispersion of certain brain colloids, and one resulting from agglomeration of those colloids. In man we have dementia praecox catatonic as a condition involving over-dispersion, and catatonia, as illustrated by Case 8 in the report of Drs. Lang and Paterson, as a condition involving agglomeration. In animals we have bulbocapnine catatonia representing agglomeration catatonia, and no certain case as yet of over-peptization catatonia.

The general conclusions of this paper are:

1. Bulbocapnine is an agglomerating agent for protein sols both *in vitro* and *in vivo*, as is shown by the egg-white test and the improved behavior of a case of dementia praecox catatonic when the alkaloid was administered.

2. Sodium rhodanate and ephedrine sulphate relieve bulbocapnine catatonia in rabbits due to their peptizing action.

3. Sodium amytal enhances bulbocapnine catatonia in rabbits due to its agglomerating action.

4. Bulbocapnine produces catatonia and catalepsy in rabbits by virtue of its agglomerating action on certain of the protein colloids in the brain.

5. There are probably two types of catatonia in animals; but no case of peptization catatonia is yet known with certainty.

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[1] Henry, *Psychiatric Quart.*, **5**, 68 (1931); Freeman: *J. Am. Med. Assoc.*, **97**, 294 (1931).

[2] Bourguignon and de Jong, *Compt. rend. soc. biol.*, **99**, 55 (1928).

[3] Bancroft and Richter, *Proc. Nat. Acad. Sci.*, **17**, 294 (1931).

[4] de Jong and Bourguignon, *Compt. rend. soc. biol.*, **99**, 57 (1928).

[5] Schaltenbrand, *Archiv ges. Physiol.* (Pflüger's), **209**, 623, 643, 653, 664 (1925).

[6] Henry, *Psychiatric Quart.*, **5**, 453 (1931).

CROSSING-OVER AND MUTATION

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Recent genetic and cytological work on translocations in *Drosophila melanogaster* seems to show that there is a high correlation between crossover frequency and mutation frequency.

The map length of the third chromosome is about 106 crossover units. Dobzhansky (1930) found that the map distance between Dichaete (40.4) and curled (50), less than 10 crossover units, represents about 40 per cent of the actual length of the chromosome. This region of the chromosome, which includes the spindle fibre attachment point, shows less than 10 per cent crossing-over and includes only 8 of the 41 mutations listed in Figure 41 by Morgan, Bridges and Sturtevant (1925). The distal ends of the third chromosome, including Dichaete at the left end, and curled at the right, constitute about 60 per cent of the cytological length of this autosome, but include more than 90 per cent of the crossover units and about 80 per cent of the listed mutations. Thus in the region of the spindle fibre there are few crossovers and few mutations, while at the distal ends of the third chromosome both crossovers and mutations are relatively frequent.

A similar relation between crossover length, cytological length and mutation has been found in the second chromosome of *Drosophila* (Dobzhansky, 1930).

The map length of the X-chromosome is about 72 crossover units. Painter (1931) found that the distance from forked to the distal end of the X, about 62 crossover units, constitutes only about 30 per cent of the cytological length of the X-chromosome. This distal segment of the chromosome includes 84 per cent of all crossovers and about 80 per cent of the listed mutations. The chromosome segment which carries the fibre attachment point at the right end includes only 16 per cent of all crossovers and only 20 per cent of the listed mutations, although this segment constitutes about 70 per cent of the cytological length of the X-chromosome.

The remarkable correlation between crossing-over and mutation, especially in the X-chromosome, seems to indicate that most of the mutations in *Drosophila* may be the result of crossing-over. This conclusion is in accord with the fact that both crossing-over and mutations are very rare in the Y-chromosome.

If mutations are produced by crossing-over, the most probable agency would be unequal crossing-over. Unequal crossing-over would produce gene duplication and deficiency or the duplication and deficiency of parts of genes or gene material. Progressive and regressive mutations should be produced in equal numbers, but progressive mutations are rare. The excess of regressive mutations might be attributed to an optimal development of the species so that an excess of specific gene material results in no further development of the specific character.

This theory of mutation can be reconciled with the behavior of multiple allelomorphs. A recessive gene need not mean the absence of specific gene material, but only a deficiency sufficient to inhibit the normal expression of the gene. Large deficiencies would be lethal and in general recessive genes should be deterious to the organism. Natural selection would tend to eliminate unequal crossing-over and thus decrease the rate of mutation.

Sturtevant (1925) has concluded that unequal crossing-over is not the cause of most mutations in *Drosophila*, but the remarkable correlation between crossing-over and mutation in different regions of the chromosomes does not seem to justify such a conclusion. Some of the mutations which cannot be attributed to unequal crossing-over may be of the same nature, however, due to deficiencies and translocations originating in somatic tissue. Other "mutations" can be attributed to the duplication or loss of entire chromosomes, the irregular distribution of chromosome fragments, or temporary inactivation of chromosomes (Clausen, 1930; Stadler, 1931).

This theory of mutation would account for differences in the rate of evolution of different organisms, differences in the rate of evolution at different periods in phylogenetic development, the genetic stability of certain genera and species over long periods of time, and the rare occurrence of mutations in most of the existing species of plants and animals. Evolution would depend, to a considerable extent, on the emergent evolution of the gene-duplication and deficiency of gene material in different quantities and in different structural combinations.

Clausen, R. E., "Inheritance in *Nicotiana Tabacum*. X. Carmine-Coral Variegation," *Cytologia*, **1**, 358–368 (1930).

Dobzhansky, T., "Translocations Involving the Third and the Fourth Chromosomes of *Drosophila Melanogaster*," *Genetics*, **15**, 347–399 (1930).

Dobzhansky, T., "Cytological Map of the Second Chromosome of *Drosophila Melanogaster*," *Biol. Zentr.*, **50**, 671–685 (1930).

Morgan, T. H., Bridges, C. B., and Sturtevant, A. H., "The Genetics of *Drosophila*," *Biblio. Gen.*, **2**, 1–262 (1925).

Painter, T. S., "A Cytological Map of the X-Chromosome of *Drosophila Melanogaster*," *Science*, **73**, 647–648 (1931).

Stadler, L. J., "The Experimental Modification of Heredity in Crop Plants," *Sci. Agr.*, **11**, 557–572 (1931).

Sturtevant, A. H., "The Effects of Unequal Crossing-Over at the Bar Locus in *Drosophila*," *Genetics*, **10**, 117–147 (1925).

A PRELIMINARY REPORT ON FUNCTIONAL PSYCHOSES

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The problem of the Dementia Praecox, Manic Depressive and Epileptic psychoses is a very serious one and any explanation tending toward a more accurate diagnostic and therapeutic approach requires earnest consideration. They are the three large groups of functional mental disorders. Many studies have been made as to the etiology, therapy and pathology, with bitterly disappointing results at times, though progress has been made. The present diagnostic classification is based partly on etiology and partly on behavior reaction. The larger groups of mental cases admitted to State Hospitals are of the so-called functional disorders. This study was made to determine whether further clarification as to diagnosis could be achieved.

Bancroft and Richter[1] have made the suggestion that "many of the functional disorders may be nothing more than an abnormal degree of

dispersion of the nerve colloids and have been classified erroneously as 'functional' due to the inability of the histological technique to reveal the colloidal abnormalities." This abnormal state may be either over-peptization or agglomeration. They review the work of many authors showing that studies have been made both with agglomerating and peptizing agents, though not systematically or consciously. They draw the conclusion that "disorders of dispersion may be benefited by coagulating agents, and disorders of decreased dispersion would be improved by peptizing agents."

They conclude that catatonia involves over-dispersion while in epilepsy there is a decreased state of dispersion. They discuss sodium amytal as a coagulating agent and sodium rhodanate, (NaCNS), as an example of the peptizing group, which also includes iodides and bromides. In another paper Bancroft and Rutzler[2] have discussed the action of these compounds in more detail.

Our work was begun at the suggestion of Professor Bancroft, who drew our attention to the need for a study of the action of these drugs. His advice and criticism was utilized freely throughout the study. We are indebted to Mr. J. E. Rutzler, Jr., for advice and assistance as to preparation, dosage and administration of sodium rhodanate. Our problem was to determine whether clinical evidence could be found to support the views of Bancroft, Richter and Rutzler. No attempt was made to select cases: a number showed marked motor activity with impulsive assaultive tendencies; others were noisy and excited; some were depressed or stuporous. A few showed little abnormal motor behavior. Forty-six cases were studied under both drugs.

Our method was to exhibit sodium amytal orally. The usual dose was 0.4 gram in twenty-four hours; but a few cases were given 0.8 gram and a few others reacted well with 0.2 gram. Cases were tested for five days and a summary made of the behavior. Forty-eight hours were allowed to elapse in order to ensure complete elimination. The sodium rhodanate was started with a dosage of 0.3 gram twice daily by mouth. This was increased at the rate of 0.3 gram per day until the case was receiving 2 grams per day. One case was given as much as 4.6 grams per day with no other result than an increase in stupor. It was found that, so far as diagnostic tests were concerned, a dose of one to two grams per day was quite sufficient and that the majority of cases would show reaction on one gram.

A few illustrative case histories are given. We prefer the terms schizoid and cycloid to dispersed and agglomerated. The blood pressures are given because it has been suggested that the improvement in some cases might be due to the drop in blood pressure and not to the specific action of the sodium rhodanate. Our studies do not confirm this view.

CASE 1. J. D. Male, aged twenty-eight, duration five years.

Diagnosis: Dementia Praecox, Catatonic.

Behavior: Before—stupor, seclusive, untidy, refused to care for personal needs. No delusions or hallucinations. Blood pressure, 108/72.

Sodium amytal intravenously, 0.5 gram in 10 cc. triple-distilled water. Blood pressure fell to 90/64, but soon recovered. Drowsy, no deep narcosis, awoke feeling refreshed, talked and smiled.

Sodium amytal orally. Slow, steady improvement. Asked for work; assisted in cleaning and polishing; fed himself; kept clothes neat, clean; in good contact with surroundings.

Sodium rhodanate. Blood pressure fell to 90/60, confused stupor reaction. Very pale. Head bowed. No response, untidy and dirty.

Sodium rhodanate stopped. Recovered so that he would obey slowly on command.

Comment: This case is one in which the blood pressure fell to the same level with each drug and yet there was marked mental improvement with sodium amytal, while sodium rhodanate made his condition worse.

This case illustrates excellently the arguments of Bancroft, Richter and Rutzler as it reacted definitely to a coagulating agent and so belongs in the over-peptized or schizoid group. The treatment should be continued, using this type of drug; but must also be accompanied by other therapeutic aids. The mental picture shows predominance of schizoid characteristics with splitting of affect from ideational content (he has put away all feeling).

CASE 2. C. S. Male, aged fifty; duration eight months.

Diagnosis: 1. Alcoholic; 2. Apathy and Depression.

Behavior: Before—shows stupor, depression, is negativistic, generally untidy but not dirty. Has to be coaxed to eat. Was fearful but could not give cause of this fear.

Sodium amytal intravenously. Within three minutes showed slight restless movements; in four minutes he was talking distinctly and responded promptly to commands, was active and alert, later he became drowsy, slept normally and awoke refreshed.

Sodium amytal orally. Became alert and interested, cared for person properly, slept well.

Sodium amytal stopped. Stupor returned promptly but was no worse than before.

Sodium rhodanate. Stupor was increased, was untidy, dirty, did not feed himself properly.

Sodium rhodanate stopped. Returned to original state.

Comment: This case was first diagnosed as alcoholic; but this was changed because of the results reported. When he was in the improved state, he described his depression as due to an unknown fear; he had the delusion that war was to occur all over the world. The schizoid tendencies predominated. There is definite splitting of affect; behavior shows severe regression; therapeutic indications are for exhibition of coagulating agents. The test indicated that a condition of over-peptization existed and that our diagnosis should therefore be schizophrenia.

CASE 3. F. P. Male, aged fifty-four, duration four months.

Diagnosis: Manic Depressive, Manic.

Behavior: Before—excited, confused, assaultive, no delusions or hallucinations.

Sodium amytal, 0.2 gram by mouth. Became very excited, showed a deep narcosis and then excitement.

Sodium rhodanate. Became quiet, showed a slow improvement. Mental condition cleared, normal state recovered. Paroled home.

Comment: We have in this individual one of the benign psychoses. He was extremely excited and his behavior was such that he required restraint. Cycloid tend-

encies predominated and there was no severe regression; behavior and thought were in contact with reality. From previous experience we believe that this case would no doubt have improved in time; but it is felt that improvement was more rapid under sodium rhodanate. We were therefore dealing with an agglomerated or cycloid state.

CASE 5. M. S. Male, aged thirty-four, duration five years.

Diagnosis: Dementia Praecox, Hebephrenic.

Behavior: Before—excited, restless, untidy, noisy with an occasional clear time when he would speak English. At other times his productions were incoherent and in German, his childhood language. Blood pressure 110/68.

Sodium rhodanate. Slow, steady improvement. He requested his own clothes, talked in English coherently and has maintained this improvement for two months. Blood pressure, 102/72.

Sodium amytal. Excited, stimulated, drowsy, short narcosis. Following this he was over-active, destructive. Showed many mannerisms, grimaces and fantastic poses; but, while he was in these bizarre attitudes that appeared catatonic-like, he only adopted them when he knew he was being observed. He enjoyed the effect of this behavior on others. This indicates the presence of a strong affect but mischievous in direction.

Comment: This is an individual whose behavior reaction under amytal would be called Dementia Praecox Catatonic. Actually in his usual state the diagnosis has alternated between Dementia Praecox Hebephrenic and Manic Depressive Mixed according to the observer. This alternation indicates that we have here a case with marked schizoid tendencies; but that affect was not split off, and was still strong, and was adapted to the situation at an adult level.

The behavior under sodium rhodanate would, according to our experimental findings, place him in the agglomerated or cycloid group which correlates with the Manic Depressive classification. The prognostic indication should be hopeful. Therapy should consist of exhibition of peptizing agents.

CASE 6. C. P. Male, aged thirty-six, duration six years.

Diagnosis: Dementia Praecox, Catatonic.

Behavior: Before—excited, noisy, restless, resistive, mute for five years; appetite is good but sleep is usually disturbed. This man wrote on the wall that he defied us to make him speak.

Sodium amytal intravenously. Sleepy, nodded in response to questions and spoke once. Narcosis of short duration, following which he was excited and required restraint to prevent injury.

Sodium rhodanate. He was depressed, confused and irritable on large doses. On small repeated doses he began writing numerous letters which were logical to some extent but showed disturbed sentence structure. On the fourth day of administration he began to talk and was over-active and irritable. On the fifth day he was still over-active. He talked steadily. He showed flight of ideas and his conversation rambling and irrelevant; but coherent and correct in choice of words and sentence structure. His ideas were in response to normal stimuli, and if they had not been so rambling and produced so fast (in other words a manic reaction), he would have been normal as to content and production of ideas. He ignored his personal appearance completely but was perfectly correct in his habits.

Comment: This is one of the mixed cases, so hard to estimate, diagnose, and treat correctly. He shows many schizoid characteristics and these predominate. The cycloid tendencies are manifested in his irascibility. There are also long mood swings between the elation which leads to excitement and the depression which produces irritability and negativism.

The interpretation of reaction is difficult in this case. To sodium amytal he reacted with excitement and violence similar to Manic Depressive; to the sodium rhodanate he showed a release of the inhibitory mechanism so that we have uncritical freedom of thought production, undirected and distractible. Our suggestion is that we have here an individual, who responds so readily to these drugs that he is normal only over a slight range. We probably gave him more than enough sodium rhodanate to bring him to the normal state. Considering his five years of mutism, his free production now, at a correct level of adult thought and in response to reality, would indicate an improved state and therefore Manic Depressive. Therapeutically it remains to find the correct dose level at which he may be maintained.

CASE 8. J. L. Male, aged twenty, duration two months.

Diagnosis: Catatonia.

Behavior: Before—impulsive, assaultive, refused food, went to bed with clothes on, was mute; marked motor activity and confusion.

Sodium amytal orally. Became more disturbed, excited, violent and assaultive, very confused, ataxic gait. Blood pressure 110/80.

Sodium rhodanate. Gradually became quiet, better behaved and clear; would sleep entire night and eat well.

Sodium rhodanate stopped. Resumed restlessness, confusion, soiled bedding and clothing, destructive; but was not assaultive or agitated.

Comment: This case was found to have a taenia saginata infestation, hgbln 65, RBC 3,510,000. The test would indicate that we are dealing with an agglomerated state and that, upon improvement of physical condition, the mental reaction would show corresponding improvement, in which case a more hopeful prognosis could be made in spite of the patient's regression to the vegetative level of behavior.

This case would substantiate the contention of Bancroft and Richter that there may be two forms of Catatonia, one the peptized and the other the agglomerated. However, we would classify this case more properly as a reactive stupor to a physical state and has a good prognosis although showing infantile behavior.

CASE 18. J. K. Male, aged twenty-four, duration three years.

Diagnosis: Epilepsy.

Behavior: Before—uneasy, talkative, restless, threatening, occasionally terrific excitement when he would require restraint to prevent injury. He would not coöperate with diet. Blood pressure 132/90.

Sodium amytal. Drowsy, deep sleep. On awakening became irritable, restless, would not work, and refused to coöperate.

Sodium rhodanate. Slow, steady improvement, became well behaved, quiet, worked occasionally on ward which he does very well; sleeps entire night which is in contrast to previous behavior. Blood pressure 128/88.

Comment: This case falls definitely in the agglomerated or cycloid type. His improvement was not accompanied by any change in blood pressure.

CASE 21. D. D. D. Male, aged twenty-nine, duration twenty-one days.

Diagnosis: Manic Depressive, Depressed.

Behavior: Before—depressed, worried, fearful, anxious, untidy in personal appearance, confused, constant supervision to prevent him from getting into difficulty; would not eat well. Blood pressure, 118/78.

Sodium amytal. Deep sleep, ataxia, became clear mentally, was happy, alert and able to discuss the situation. While in this state he was able to tell us of his fears, anxieties and delusions of persecution, and ideas of bodily harm.

Sodium rhodanate. Became sulky, sarcastic, noisy, irritable and violent, slept fairly well at night. Blood pressure, 112/70.

Comment: Again we find our tests indicating that our classification was wrong, that it was based on the symptoms presented to us by the patient and not on knowledge of his mental state. When contact was made, we then found a delusional state with fears and ideas of persecution, indicating a schizophrenia. He presents an over-peptized state that is improved by agglomeration. Because of our more adequate information we do not now consider that he is a case of Manic Depressive.

CASE 24. L. C. Male, aged forty-six, duration two months.

Diagnosis: Involution Melancholia.

Behavior: Before—depressed, anxious, fearful, worried, constantly complaining of somatic difficulties. Restless at night, could not sleep. Blood pressure, 178/100.

Sodium amytal. More interested, alert, some improvement, deep sleep.

Sodium rhodanate. Appeared uneasy, stuporous, confused, did not talk, but slept well at night. Blood pressure, 146/80.

Comment: We find here that more definite information as to the mental content was obtained when the patient was able to discuss the situation more freely under sodium amytal. The somatic ideas were predominant and delusional in character. Schizoid tendencies predominated; this has been recognized in Involution Melancholia so that in this classification we have two types—one benign or cycloid-predominant which would recover, and the other schizoid-predominating with a poor prognosis.

The whole forty-six cases are summarized in table 1. Eight out of the forty-six cases are classed temporarily as inconclusive. From the

TABLE 1

DIAGNOSIS	SODIUM AMYTAL IMPROVED	SODIUM AMYTAL WORSE	SODIUM RHODANATE IMPROVED	SODIUM RHODANATE WORSE	INCONCLUSIVE	TOTAL
Dementia Praecox Paranoid	1	2	2	3	2	5
Dementia Praecox Catatonic	5	1	1	5		6
Dementia Praecox Hebephrenic	3	1	1	3	1	5
Alcoholic	1	1	1	1		2
Manic Depressive Manic	4	7	7	4		11
Manic Depressive Depressed	1	1	1	1		2
Manic Depressive Circular		2	1		1	2
Catatonia (?)		1	1			1
Excitement (Mental Deficient)		1	1			1
Epilepsy		4	4			4
Involution Melancholia	2			2		2
General Paralysis		2	1		1	2
Endocrinopathy		1			1	1
Diabetes		1	1		2	2
						46

table we find that the Dementia Praecox groups are improved by administration of sodium amytal. The cases that are apparently made worse and the inconclusive cases are ones about which we have been in doubt as to exact diagnosis, having alternated between Manic Depressive and Dementia Praecox. Our Involution cases were improved by sodium amytal. This corroborates very well the view that there is a large schizoid factor in those cases which do not clear up at all readily. The Manic Depressive group is definitely improved by sodium rhodanate, while they are made worse under sodium amytal with a tendency to increase

of excitement. The discrepant cases are also borderline cases of Manic Depressive and show many schizoid factors that have caused the diagnosis to be questioned. They are improved by sodium amytal and so would indicate a more proper diagnosis of schizophrenia. The inconclusive case is listed so because of the presence of arteriosclerosis and chronic myocarditis.

The epileptics are made worse by sodium amytal and show improvement to sodium rhodanate. In the excited case of Mental Deficiency, the behavior reaction would classify it under the Manic Depressive groups. Improvement with sodium rhodanate would be expected and did occur.

In the two alcoholics, one reacted with improvement to sodium rhodanate as one would have expected. The other was improved by sodium amytal;

TABLE 2

BLOOD PRESSURES*

	CASE	BEFORE	AFTER	S.A.	S.R.	SCHIZOID	CYCLOID
5	D. P. H.	110/68	102/72[1]	−	+		+
8	Catatonia	110/80					
9	M. D.	110/60					
10	Manic	130/60	116/68[1]	−	+		+
11	Manic	118/80	122/82[1]	−	+		+
12	G. P. I.	120/75					
14	M. D. M.	108/66	100/62[1]	−	+		+
16	M. D. M.	120/80	106/60[2]	−	+		+
17	M. D. C.	220/	102/60[2]	−	+		+
18	Epilepsy	132/90	128/88[1]	−	+		
19	M. D. M.	160/100	118/74[2]	−	+		+
21	M. D. D.	118/78	112/70[1]	+	−	+	
22	G. P. I.	160/90	128/80[2]		Inconclusive		
23	M. D. M.	180/90	142/80[2]	−	+		+
24	Involution	178/100	146/80[2]	+	−	+	

* From a study, in preparation by Dr. Robt. Wise, Willard State Hospital.

[1] Slight changes that are easily within normal variation.

[2] Very definite changes in blood pressure. Only four show changes in the systolic pressure of over ten points (Hg).

but it was found that he had a delusional trend with splitting of emotional field, so that it should more properly be diagnosed as Schizophrenia. Only two cases of General Paresis were dealt with. Both have received large amounts of tryparsimide. One, the inconclusive case, was under treatment at the time, so that the sodium rhodanate had to be discontinued. He furthermore shows very severe neurological involvement.

The two diabetics fall in the inconclusive group. One showed a mixture of schizoid and cycloid characteristics with predominance of cycloid, and is receiving forty units of insulin per day. Much further study on this case is required before positive statements can be made. He, however, was excited under sodium amytal. The other one showed predominance

of cycloid characteristic and gave a narcotic reaction with sodium amytal but showed improvement under sodium rhodanate. The case of Endocrinopathy was a mixture of schizoid and cycloid tendencies with mood fluctuation and regression in behavior. Because of the alternation between excitement and quiescence, we could not avoid the consideration of a coincidental factor in the exhibition of our drug.

The data in regard to blood pressures are tabulated in table 2. Of the twelve cases observed, six showed slight changes of blood pressure that were easily within normal variation and six showed very definite changes. These are summarized as follows:

CASES SHOWING SLIGHT OR NO CHANGE

D. P. H.	1	Improved by rhodanate
Manic	4	3 Improved by rhodanate 1 Improved by amytal
Epileptic	1	Improved by rhodanate

CASES SHOWING MARKED FLUCTUATION

Manic	4	4 Improved by rhodanate
G. P. I.	1	No reaction
Involution	1	Improved by amytal

There is no evidence from these observations that a fall in blood pressure is necessarily connected with improvement of the mental state.

Conclusions.—It is our opinion:

(1) That this study has demonstrated definitely that the functional psychoses show a correlation between the syndromes presented and the state of dispersion of the cell colloids.

(2) That in schizophrenia (Dementia Praecox) the colloidal system is in a state of over-dispersion.

(3) That in the manic depressive psychoses the colloidal system is in a state of agglomeration or decreased dispersion.

(4) That, although only four epileptics were observed, the reaction was so definite as to indicate an agglomerated state of the colloidal system.

(5) That catatonia is correlated with a state of over-dispersion.

(6) That benign stupor reactions, although appearing very like catatonia, react to tests as though they are of the agglomerated or cycloid state.

(7) That, based upon the correct appreciation of the colloidal states in these syndromes, a more rational therapeutic approach may be made in the treatment of such cases.

It is not suggested that, in psychoses of organic origin, these drugs are the sole method of treatment, but only that they may be used as an aid in determining the effect of such causes on the brain colloids. Known

and applicable methods of treatment should and must be applied; but a greater appreciation of the effects of such therapy can now be made.

Blood-pressure observations were too few in number to warrant drawing any conclusions. They indicate, however, two types of cases, in one of which the blood pressure falls appreciably and in the other of which there is no definite change. Mental improvement was equal in both groups, all but one case in each group being improved.

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[1] W. D. Bancroft and G. H. Richter, *Proc. Nat. Acad. Sci.*, **17**, 294 (1931); *J. Phys. Chem.*, **35**, 1606 (1931).

[2] W. D. Bancroft and J. E. Rutzler, Jr., *Proc. Nat. Acad. Sci.*, **17**, 186 (1931).

THE HEATING OF LIQUIDS BY THE ABSORPTION OF SOUND, AND ITS RELATION TO THE ENERGY OF INTENSE HIGH-FREQUENCY SOUND WAVES

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Recent precision measurements of the velocity of sound in liquids[1] have revived interest in the absorption of sound, for in order to interpret the velocity as a thermodynamic quantity it is necessary to have definite knowledge of the departure from adiabatic conditions in compressional waves. The "supersonic" waves of Wood and Loomis[2] appeared to offer a means of measuring absorption over an extended range of conditions, since these investigators noted large heating effects due ostensibly to sound absorption. An investigation of this phenomenon, pursued fitfully since 1928, has demonstrated that the heating of liquids by sound is far more difficult to measure than was at first supposed. The results obtained are here reported because it is believed that they represent the practical limit of precision, because they indicate that many previous published statements are erroneous, and because it is hoped that they will prove valuable in the investigation of other phases of sound wave activity. Since they are somewhat unsatisfactory and of little general interest, they will be presented as briefly as possible. Numerical data are meaningless unless quoted with elaborate circumstantial detail, and will hence be almost wholly omitted.

When a liquid, in its containing vessel, is subjected to intense high-

frequency sound waves it may be heated by several agencies other than the absorption of sound by the liquid itself. The most important of these is dielectric loss in the liquid produced by the oscillating electric field which piezoelectrically generates the sound waves. Heating of this type, which has been made the subject of a special investigation,[3] may be eliminated by shielding the liquid in a grounded Faraday cage. Again, the liquid may be heated indirectly by the contact of its containing vessel with the oil which transmits the sound waves from the oscillating crystal. Since the oil cannot be electrically shielded it suffers heating by dielectric loss as well as by absorption of sound. An extended series of observations has demonstrated that almost 90% of the heating of electrically shielded liquids disappears when the oil is adequately thermostated. Finally, the liquid may be heated if its containing vessel absorbs sound. This effect is difficult to eliminate, since the liquid must be shielded electrically. Careful observations with the type of containing vessel employed below have shown its contribution to the total heating of the liquid to be of secondary importance, and it will therefore receive no further consideration.

The apparatus illustrated in figure 1 is designed to eliminate or control these sources of error as far as possible. Dielectric loss in the liquid is prevented by the use of grounded brass containing vessels. Thermostating is secured by pumping 30 liters of oil a minute through the 0.5 cm. space which separates the bottom of the containing vessel from the crystal. So large a volume of oil may appear excessive, but experiment has demonstrated that it is barely adequate. Accidental errors are further reduced by comparing each measurement of absorption by the liquid with a similar measurement in which the liquid is contained in a brass tube with an opaque bottom. The second of these results is subtracted from the first to obtain the genuine heating due to absorption by the liquid itself. This must then be corrected for the cooling effect of the thermostating oil by subjecting the liquid to radiation for varying periods of time, plotting the heating calculated per minute of radiation against the time of raying and extrapolating to zero time.

The construction of vessels with bottoms transparent or opaque to sound has been made possible by the work of R. W. Boyle and his collaborators.[4] It has been shown theoretically, by reasoning similar to that employed in interference spectroscopy and confirmed experimentally under conditions somewhat similar to those here under consideration, that a medium will transmit sound wholly only if its thickness is an exactly integral multiple of its half wave-length of sound. For other thicknesses it becomes more or less reflecting depending on its thickness, density, and adiabatic elasticity and the density and elasticity of the surrounding medium. In the experiments quoted below the thickness of the brass

plate on the bottom of the tubes used for absorption measurements in liquids was 0.003 cm., and for control measurements 0.31 cm., which indicates, according to Boyle's expression, that the first was about 92%, and the second only 1% transmitting at 314 k.c.

Temperature differences between pairs of irradiated tubes were measured

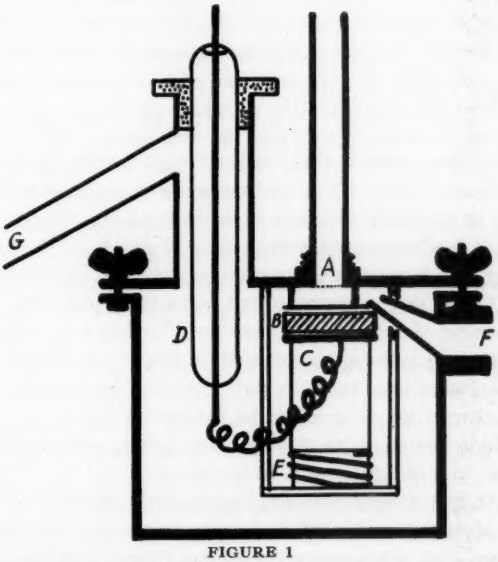

FIGURE 1

Apparatus for the study of the heating of liquids by absorption of sound.

Interchangeable brass tubes with thin or thick brass bottoms are screwed in at A immediately above the crystal B. The high tension electrode C which is connected through the oil-filled glass tube D, maintains the crystal against the upper grounded electrode by gentle pressure of the spring E. A stream of oil entering at F is directed against the bottom of the tube A by a special nozzle, and leaves the apparatus through G, whence it falls into a large reservoir and is pumped in again at F after being brought to constant temperature.

to about 0.005°C. by a triple copper-constantin thermoelement. No indications of rectification of the high-frequency field were noted in the thermoelement circuit, but it was found impossible to make temperature measurements during radiation owing to the absorption of sound by the thermoelements.

A series of observations were made with a power input of 1.63 k.w. at

314 k.c. in order to compare the heating of water with that of various aqueous solutions and suspensions. The result of two determinations of the heating of water under these conditions are given to indicate the reproducibility of the results. The figures are fully corrected, and represent the heating in °C. per minute due to the absorption of sound by 25 cc. of water in brass tubes of 1.72 cm. inside diameter.

Determination 1.

0.73	0.71	0.56	0.58	0.67	Average 0.65°C.

Determination 2.

0.70	0.76	0.63	0.73	0.62	Average 0.69°C.

It is hardly to be expected that, with so small a total effect and a reproducibility of only some 10%, various aqueous solutions should behave in a manner appreciably different from pure water. Sugar and glycerine solutions of viscosities respectively 3×10^{-2} and 8×10^{-2} in c. g. s. units showed no greater heating within experimental error. Similarly a "physiological" salt solution, a concentrated vanadium pentoxide sol and an aqueous emulsion of rosin, which were tested in the hope that an explanation for certain physiological anomalies might be found in abnormal sound absorption, conformed to pure water. An attempt to detect a difference between an air-free and a cavitating liquid met with failure. Organic liquids heated more rapidly than water, and roughly in inverse ratio to their specific heats, as is to be expected.

It might at first appear that the height of the liquid column above the crystal would importantly influence the amount of heating which the liquid suffers. For if resonance conditions should be established between the highly reflecting liquid-air interface and the surface of the crystal the energy density in the liquid could build up to far greater values than if the liquid were of infinite extension. A simple geometrical analysis of an enlarged photograph of a meniscus of suitable proportions shows, however, that less than 10% of the air-liquid interface is flat enough to give resonance under the conditions described above. It shows also that a small proportion of the sound which enters must be permanently trapped in the tube owing to the sharp upward curvature of the edges of the meniscus. This phenomenon cannot, however, be treated quantitatively even with an idealized plane wave, since the ordinary reflection laws do not apply in spaces so small compared to the half wave-length of sound.

A series of observations were also made in an attempt to obtain a liquid which, in a column of reasonable length, would totally absorb all entering sound waves. Petroleum jelly, glycerine and the like gave about twice as much absorption as water, but were highly unsatisfactory for this purpose because their viscosity was so great that adequate measurement of their average temperature was impossible. The procedure was, there-

fore, modified by substituting for a liquid, the rise in temperature of which could directly be measured, a totally absorbing solid plug of known cross-section. The plug was transferred, after a determined period of radiation, to a Dewar flask calorimeter containing a known volume of water at a known temperature. The rise in temperature of the water, when suitably corrected for the heat capacity of the flask, gave directly in calories the energy absorbed by the plug and hence indirectly the energy density of the sound waves. The advantage of this method is that it is not concerned with the temperature rise, heat capacity or mechanical properties of the plug. The results so obtained, provided that the plug is totally absorbing and is adequately shielded electrically, must represent a lower limit for the energy of the sound. The cooling effect of the oil in which the plug is immersed may be ascertained as before by plotting the heat collected calculated per minute for different irradiation times, against time of radiation, and extrapolating to zero time. It is advisable to choose a radiation time such that the plug absorbs only some 10 calories per square centimeter, in which case the oil cooling is less than 5% and may be neglected.

Since the plug must be totally absorbing, the material of which it is constructed is of some importance. It was found that, with sound energies of some 50 cals. per minute per cm.^{2}, bakelite, fibre, hard rubber and pitch of suitable length and cross-section gave, when adequately shielded electrically, identical results for the total sound absorbed. Glass, metals, celluloid and several other substances of comparable dimensions indicated that they were not totally absorbing by giving greatly inferior values. The totally absorbing materials had in common the property that, for a given cross-section and sound intensity, the energy which they absorbed varied with their length from almost zero for very thin segments to a maximum for segments of 2 cm. or more. When the maximum had been attained the energy absorbed became independent of length for several centimeters. This behavior, coupled with the identical values given at a determined intensity by different materials, is considered adequate proof of total absorption.

The absorbent plugs finally adopted were constructed by pouring molten pitch into a lightly soldered cylindrical brass cup 6 cm. high and 2.5 cm. in cross-section constructed from 0.0026 cm. brass stock. The plug was then trimmed to a suitable length and closed by soldering. Any other strongly absorbing material is equally suitable, although many are difficult to shield without the inclusion of reflecting air-bubbles.

The results obtained by this method, although reproducible to 1% with suitable precautions, probably do not represent the actual intensity of sound to better than 10%. Previously, however, even the order of magnitude of the energy density was in doubt.

The sound energy output of the Wood and Loomis apparatus varies from 152 calories min.$^{-1}$ cm.$^{-2}$ for an input of 2.5 k.w. to 17.6 cals. min.$^{-1}$ cm.$^{-2}$ for an input of 1.3 k.w. From this it will be seen that the output in sound is not a linear function of the input energy, as is, indeed, to be expected. The maximum ratio of output to input occurred, at 400 k.c., with an input of about 2.2 k.w. At this point the results became difficult to reproduce owing to the variability of the corona discharge from the high-tension circuit. This variability, which explains many inconsistencies observed in the quantitative study of phenomena produced by sound waves, disappears at low input energies.

Under the conditions used for the heating of water four measurements gave 19.0, 18.4, 19.2 and 18.7 or, averaging, 18.8 cals. min.$^{-1}$ cm.$^{-2}$ output of sound. Of this, 8.3 cals. min.$^{-2}$ cm.$^{-2}$ were absorbed by a 12-cm. column of liquid according to the measurements quoted above. Although the absorption coefficient of water for sound at this frequency is unknown it is incredible that the intensity should be diminished almost 50% owing to absorption by passage through some 120 half wave-lengths. It is necessary to conclude, therefore, that the sound is reflected many times between the meniscus and the crystal before it is converted to heat. The actual energy density in a tube with reflecting boundaries may, therefore, be far greater than that corresponding to the average output of sound of the source.

The heating observed for 25 cc. of water with maximum input wattage was about 2.5°C. per minute corresponding to 28 cals. min.$^{-1}$ cm.$^{-2}$ and showing a less efficient input-absorption ratio. This indicates that the results recorded by previous investigators of 10°C. per minute were due mainly to dielectric loss and oil heating.

There is, of course, no definite limit for the temperature which can be produced locally owing to the absorption of sound. Temperatures of 200°C. have been produced over areas of 10 cm.^{2}, and 500°C. has been attained in very limited regions by suitable experimental arrangements.

Summary.—The heating of water and dilute aqueous solutions by absorption of high intensity ultrasonic waves has been quantitatively measured. A method employing total absorption for the estimation of the intensity of an ultrasonic source is described.

[1] J. C. Hubbard and A. L. Loomis, *Phil. Mag.*, **5**, 1177 (1928). A. L. Loomis and J. C. Hubbard, *J. Optical Soc. of America*, **17**, 295 (1928).

[2] R. W. Wood and A. L. Loomis, *Phil. Mag.*, [7], **4**, 417 (1927).

[3] W. T. Richards and A. L. Loomis, *Proc. Nat. Acad. Sci.*, **15**, 587 (1929).

[4] R. W. Boyle and W. F. Rawlinson, *Trans. Roy. Soc. Canada*, **22**, 55 (1928). R. W. Boyle and D. K. Froman, *Canadian J. Res.*, **1**, 405 (1929).

THE CRYSTAL LATTICE OF CALCIUM METABORATE, CaB_2O_4

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In the present paper are given briefly the results of a structure determination of calcium metaborate. For a more detailed account I may refer to another paper that will appear later in *Zeitschrift für Kristallographie*.

Crystals of calcium metaborate are orthorhombic.[1] The unit cell containing 4 molecules CaB_2O_4 was found to have the dimensions

$$a = 6.19 \text{ Å} \qquad b = 11.60 \text{ Å} \qquad c = 4.28 \text{ Å}$$

corresponding to the axial ratio 0.534:1:0.369. The space group is $Pnca(V_h^{14})$, and the atoms are distributed among the available positions of the space group as follows:

$$4 \text{ Ca on twofold axes: } \pm(1/4\,Ou)(1/4,\ 1/2,\ 1/2+u)$$

8 B, 8 O_I and 8 O_{II} are all lying in general positions:

$$\pm(xyz)(x,\ 1/2-y,\ z+1/2)(x+1/2,\ 1/2-y,\ 1/2-z)(x+1/2,\ y,\ \bar{z}).$$

The values of the ten parameters involved were determined on the basis of the intensities of the reflections observed in oscillation photographs. Table 1 shows the final parameter values.

TABLE 1

THE PARAMETER VALUES

	IN ANGULAR MEASURE			IN FRACTIONS OF CELL DIMENSIONS		
	$2\pi x$	$2\pi y$	$2\pi z$	x	y	z
Ca	90°	0°	95°	0.25	0	0.26
B	43°	71°	317°	0.12	0.20	0.88
O_I	45°	75°	70°	0.125	0.21	0.19
O_{II}	40°	32°	270°	0.11	0.09	0.75

These values account satisfactorily for all observed intensities. In table 2 are given the observed intensities and the calculated structure amplitudes for the spectra *hkO* and *Okl*. The *F*-curves recently published by James and Brindley[2] were used in the calculations.

In the lattice each calcium atom is surrounded by eight oxygen atoms, two O_I at a distance of 2.56 Å, two O_{II} at 2.46 Å, two O_{II} at 2.48 Å and two O_{II} at 2.58 Å. The mean distance Ca—O is 2.52 Å, which agrees favorably with the value 2.49 Å derived on the basis of the ionic radii given by the author.[3]

Three oxygen atoms (two O_I and one O_{II}) form an almost equilateral triangle around each boron atom. The B—O distances are: 1.35 Å, 1.35 Å and 1.38 Å. The edges of the oxygen triangle are 2.35 Å, 2.36 Å and 2.37 Å. In hambergite, Be_2BO_3OH, the present author found B—O = 1.35 Å and O—O = 2.35 Å.[4]

Each O_I atom is linked to two boron atoms and one calcium atom, whereas each O_{II} atom is linked to one boron and three calcium atoms.

TABLE 2

COMPARISON BETWEEN OBSERVED AND CALCULATED INTENSITIES

hkO	SIN θ	INT. OBS.	$F_{calc.}$	*Okl*	SIN θ	INT. OBS.	$F_{calc.}$
020	0.0610	vw	23	020	0.0610	vw	23
200	0.1143	s	−52	011	0.0882	nil	6
210	0.1183	vs	−92	040	0.1220	s	55
040	0.1220	s	55	031	0.1234	ms	− 29
220	0.1296	m	−55	002	0.1655	vs	−119
230	0.1464	nil	− 4	051	0.1736	w	19
240	0.1672	s	−57	022	0.1764	m	− 43
060	0.1831	w	26	060	0.1831	w	26
250	0.1906	vw	−16	042	0.2057	m−	− 40
260	0.2158	ms	−51	071	0.2291	vw	− 18
400	0.2286	vw	−26	080	0.2441	nil	8
410	0.2306	nil	− 5	062	0.2468	w−	− 15
420	0.2366	ms	67	013	0.2502	nil	2
270	0.2422	vw	2	033	0.2646	m	35
080	0.2441	nil	8	091	0.2868	nil	− 1
430	0.2462	w−	− 9	053	0.2914	w−	− 17
440	0.2592	wm	42	082	0.2949	vw	− 23
280	0.2695	w	−39	0.10.0	0.3051	s	81
450	0.2748	nil	− 3	073	0.3275	w	28
460	0.2928	wm	49	004	0.3310	w−	40
290	0.2974	w	47	024	0.3366	m−	46
0.10.0	0.3051	s	81				
470	0.3128	nil	5				
2.10.0	0.3258	w	−31				
480	0.3344	wm	60				
600	0.3429	w	−42				
610	0.3443	vw	38				
620	0.3483	w	−37				
630	0.3549	nil	− 3				

The sum of the strengths of the valence bonds ending upon the oxygen atoms is thus 2.25 and 1.75, respectively. This result is in agreement with Pauling's principle of balanced valence.[5]

The distance of closest approach of two oxygen atoms belonging to different BO_3 groups is 2.75 Å, which is somewhat smaller than the value 2.99 Å deduced from the ionic radii of the author.[3]

As all the BO_3 groups are oriented parallel to the *a*-face, strong negative

birefringence will be the result, the a-axis being the acute bisectrix.[1] The observed perfect cleavage parallel to the a-face is accounted for by the structure; there is only one Ca—O bond per 12.5 Å^2 crossing the a-face.

The most interesting feature of the structure is the presence of endless strings of BO_3 groups parallel to the c-axis. The average composition of each string is BO_2. In figure 1 is shown a section of one of these strings.

Valuable information about the nature of borate crystals is obtained

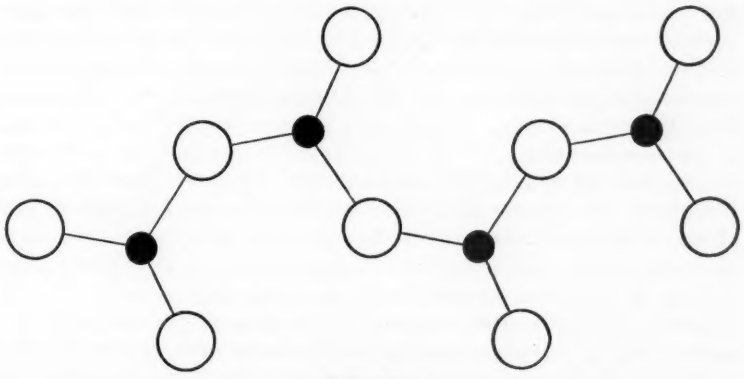

FIGURE 1

Fig. 1 represents a section of one of the endless strings of BO_3 groups viewed along the a-axis. Small solid circles are boron atoms, large open circles are the oxygen atoms. The strings are parallel to the c-axis. The section shown in the drawing extends through two unit cells.

from this investigation. Considerations of the structure of borates in general will be the subject of another paper.

I am indebted to Mr. L. G. Hall for the preparation of the crystals and to Mr. G. E. Ziegler for taking some of the photographs.

[1] Groth, *Chemische Krystallographie*, Vol. 2, 737, 1908.
[2] James and Brindley, *Zeitschr. Krist.*, **78**, 470, 1931.
[3] W. H. Zachariasen, *Ibid.*, in press.
[4] W. H. Zachariasen, *Ibid.*, **76**, 289, 1931.
[5] L. Pauling, *J. Amer. Chem. Soc.*, **51**, 1010, 1929.

A SEARCH FOR AN ELECTROSTATIC ANALOG TO THE GRAVITATIONAL RED SHIFT

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A well-known consequence of the general theory of relativity is that the observed frequencies of spectral lines in a source of light depend on the difference of gravitational potential between the locations of the source and the observer. The possibility of a similar dependence of frequency on electrostatic potential has led the writers to perform the experiment described in this paper. An effect of the sort would evidently require to be taken into account in the formulation of a satisfactory unified field theory, and by an extension of the theory of Zwicky (*Proc. Nat. Acad. Sci.*, 1929, Vol. 15), would be involved in the question of the red shift observed in distant nebulae. We have been the more inclined to undertake the exacting and delicate work because it has required only a modification of apparatus devised for another purpose.

The experiment consists essentially in comparing the frequency of a spectral line in a suitable source at zero potential with that of the same source under identical conditions except that its electrostatic potential is raised or lowered, the observing apparatus being at zero potential in both cases.

Apparatus.—The source was an electrodeless discharge in mercury vapor. The discharge tube contained a pool of mercury outside of the arc, and was surrounded by boiling carbon tetrachloride and connected to vacuum pumps through a heated capillary tube. By this means the tube was kept at a low constant temperature so as to yield sharp lines, and since the pressure of mercury vapor was below the vapor pressure corresponding to the existing temperature, there was no Doppler effect in one direction such as might have occurred if there were a net transport of atoms due to evaporation and subsequent condensation elsewhere of the mercury. An asymmetrical Doppler effect corresponding to a velocity of only a few centimeters per second would have been objectionable.

By way of eliminating Stark effects, the source and accessory pumps and oscillator tubes were mounted in a heavy copper enclosure of which the necessary ventilating openings were covered with conducting screening and the window with a glass cell containing a transparent electrolyte. Possible effects on the source of any small electrostatic force resulting from imperfect shielding could be eliminated from the final result by simply comparing frequencies obtained with shielding positive with those for equal negative potential. This is so since reversing sign of potential

merely reverses direction of stray field, and this is equivalent to reversing direction from which source is viewed. Current was supplied to oscillator and pumps at constant voltage by suitable insulating transformer. The mercury in the discharge tube was connected to the shielding, which could be kept at a steady potential of about 50,000 volts above or below ground by means of a transformer and a rectifier.

The light was received in an interferometer of the Michelson type built almost completely of fused quartz and contained in a vacuum chamber in a water-bath at temperature constant to within 10^{-3} degrees C. The vacuum is necessary in order to keep optical path-difference constant. The interferometer is compensated for temperature so accurately that the permitted variation produces a variation in path of only 10^{-5} wave-lengths. The fixed difference of path is some 582,000 wave-lengths of the line 5461 which was used. Sections of the interference pattern (a system of concentric rings) were automatically photographed in such a way that exposures taken with source at high potential were interleaved with those for zero potential. By this procedure errors due to differences among individual photographic plates were minimized. The interferometer was at zero potential throughout the experiment.

A simple comparator was employed in which the interference rings to be measured are compared directly with those on a nearly identical reference plate. With this device each exposure can be measured with a probable error corresponding to a variation in path-difference of about 10^{-3} wave-lengths. That is, the probable error for each exposure corresponds to a variation of frequency of one part in $1000 \times 582{,}000$ or 1.7 in 10^9.

Data and Results.—Eighteen pairs of exposures were taken in the comparison of frequencies for positive and for ground potential, and sixteen pairs for negative and ground potential. The first series, which was the more carefully measured, indicated a change of frequency of only 1.1 ± 0.8 parts in 10^{14} per volt; the second a change of 3.1 ± 1.6 parts in 10^{14} per volt. Both changes were in the same direction. These values were so nearly the same as their probable errors as to indicate clearly a null effect. Even if they were regarded as real, the fact that both are of the same sign shows that they cannot be due to a simple linear potential relation.

Summary.—An attempt is made to determine whether the frequency of light is affected by a difference in electrostatic potential between the source of light and the measuring apparatus. The source is an electrodeless discharge in mercury vapor which can be kept at a potential about 50,000 volts above or below ground. The apparatus for measuring the change in frequency is a quartz interferometer of the Michelson type with a fixed path-difference of 31.8 centimeters, in an evacuated case and kept

at constant temperature. With this and a special comparator it is possible to detect an extremely small change in frequency.

No effect due to potential was found.

We are greatly indebted to Dr. Jesse DuMond and Dr. Archer Hoyt for assistance and advice in connection with the high-voltage apparatus.